THE INTRODUCTION OF ROOF BOLTING TO U.S. UNDERGROUND COAL MINES (1948-1960): A CAUTIONARY TALE

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ABSTRACT

Perhaps the most significant development in coal mine ground control during the last century was the introduction of roof bolting during the late 1940's and 1950's. From an engineering standpoint, roof bolts are inherently more effective than the wood timbers they replaced. Roof bolts promised to dramatically reduce the number of roof fall accidents, which then claimed hundreds of lives each year, and they were initially hailed as "one of the great social advances of our time." Roof bolting also emerged at a time of rapid technologic transformation of the coal industry, and greatly accelerated the transition to trackless, rubber-tired face haulage.

The U.S. Bureau of Mines quickly became the new roof support's strongest advocate. Some state agencies and miners were skeptical at first, but nearly everyone was soon won over. Case histories were reported showing that roof falls could be largely eliminated while productivity increased dramatically. Little wonder that, in the words of one contemporary observer, "roof bolting has been adopted more rapidly than any other new technology in the history of coal mine mechanization."

Yet by the end of the 1950's, it was clear that roof fall fatality incidence rates had actually *increased.* It would be another decade before the superior ground support provided by roof bolts would clearly save lives. The story of how roof bolting was implemented by the mining industry, but took so long to live up to its promise, is a fascinating example of the interaction between economics, technology, regulation, and science. It still has important lessons for today.

INTRODUCTION

The 20th century was a time of continuous revolution in underground coal mining technology. At the beginning of the century, traditional pick mining with hand loading was nearly universal. Undercutting machines had largely replaced picks by 1930, when mechanical loading began the first great transformation of mining (figure 1)[1]. Other revolutionary developments included the replacement of drilling and blasting by continuous miners during the 50's and 60's and the rapid growth of longwall mining during the 1980's.

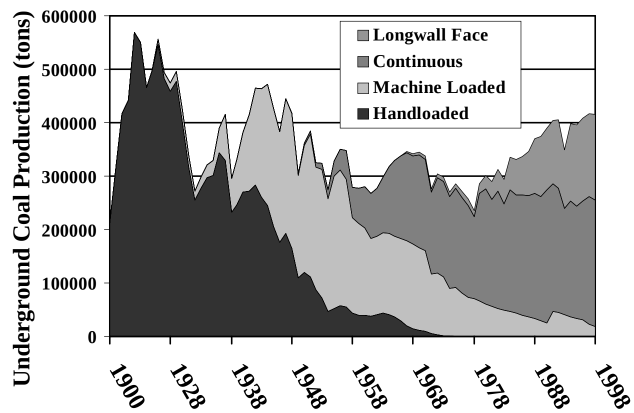

Figure 1. Underground coal mining methods of the 20th Century.

These technological changes were accompanied by equally dramatic developments in work organization, government regulation, and mine safety. Where the hand-loader worked independently and seldom saw a foreman, today's mines are highly organized and supervised. Mine inspectors were rare 100 years ago, while today many large mines are inspected nearly every day. And while coal mines once claimed thousands of lives each year, annual fatalities are now numbered in the tens.[2]

Yet at least one aspect of mining remained constant. Throughout the century, falls of roof were the greatest single safety hazard in underground coal mines. In fact, roof falls were responsible for between one-third and one-half of mining fatalities in each decade. To be sure, the same period saw a dramatic improvement in the annual fatality record measured either by the total number or by the rate per-hour per-million hours of miner exposure (figures 2 and 3). One logical explanation for this reduction is the application of new ground control technology.

Without a doubt, roof bolting has been the single most important technological development in the field of ground control in the entire history of mining. Bolting was substituted for timbering in U.S. underground coal mines in the late 1940's, and it was "accepted by the mining industry with greater rapidity than any other mining change since the inception of mechanization."[3] It has generally been assumed that roof bolting just as quickly reduced the toll taken by roof falls. Yet the real story, as it emerges from careful analysis of the accident data and the words of the participants, was far more complex.

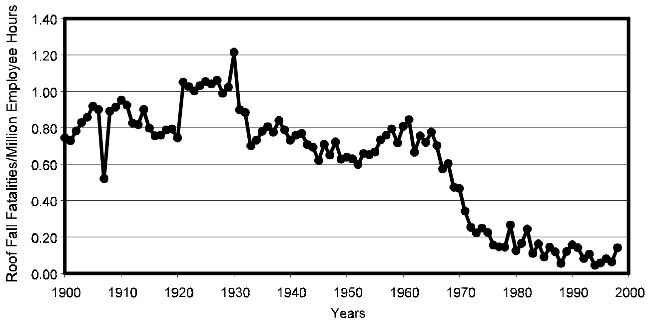

Figure 2. Roof fall fatalities in underground coal mines.

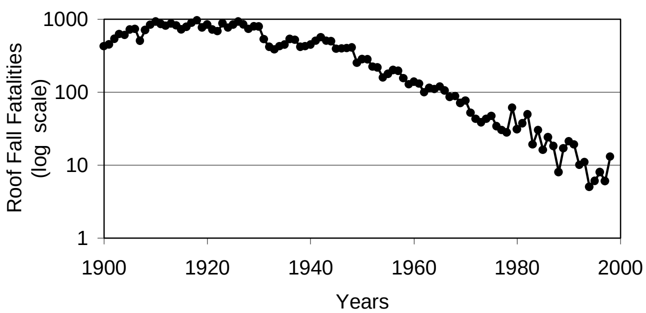

Figure 3. Roof fall fatality rate for underground coal mines (fatalities per million employee hours).

"Miner—Be Careful!"
ROOF CONTROL DURING THE HAND-LOADING ERA

At the turn of the century, roof support was considered the responsibility of each individual miner. It was his duty to "examine his working place before beginning mining work, to take down all dangerous slate, and make it safe by properly timbering it before commencing to mine coal."[4] The mine operator was responsible for delivering timbering materials to each working place, and the foreman checked that it was installed properly on his daily visit.[5]

The miners often had considerable discretion about the amount of support they installed. In weak shale roof, posts might be set 2.5 to 5 ft apart,[6] but where the roof rock was strong, no posts might be set at all. An important element in early roof support systems were "safety posts," which were set at the end of the track to protect miners while they loaded the coal or prepared the face for the next shot (figure 4).[7] These temporary supports required extra time and effort, and their use was often at the discretion of the miner.

Under these circumstances, it is understandable that much of the blame for roof fall accidents was placed on the inexperience and carelessness of the miners themselves.[8] In 1912, the US Bureau of Mines (Bureau) asked: "How can you, the miner, escape harm from roof falls?" The answer was: "Be careful…do not take the risk of loading a car before putting up a prop…set extra posts, even though they are in your way."[9]


Figure 4. Hand loading with a safety post.

Over time, however, safety professionals began to recognize that "a condition responsible for many fatalities from falls of roof is the absence of any policy on the part of management with respect to systematic methods of roof inspection and support."[10] Encouraging mine managers to prepare, promulgate, and enforce a *systematic timbering plan* became a key element in the Bureau's roof control efforts. Violations of the timbering plan would include:

- Timber too far from the face;
- Working under loose roof or loose roof not taken down;
- Props insecurely set;
- Spacing between posts too great, and;
- Safety post not set up.[11]

The Bureau also exhorted miners to "comply with systematic methods of timbering, where such systems have been adopted, and exercise judgment in placing additional posts for your own protection."[12] But so long as the typical mine foreman was responsible for about 80 miners, and seldom spent more than 5 minutes with each one during a shift, enforcing timber plans presented a challenge.

"Mining Companies Are Continuously Searching for Improved Types of Roof Support"
THE IMPACT OF MECHANIZED MINING ON ROOF CONTROL

Between 1930 and 1948 the portion of underground coal that was loaded by machine rose from less than one-tenth to nearly two-thirds.[13] Mechanized mining allowed for increased supervision, because "it was possible to obtain the desired production with a smaller number of miners and fewer working places than hand mining."[14] In addition, timbering often became the responsibility of a special crew, paid by the day rather than the ton.[15]

Unfortunately, in many ways machine mining in fact made roof support more difficult. Most importantly, loading machines required a prop-free front in which to work. The machine operator was usually protected by posts and crossbars, but the helper had to venture into the unsupported face zone (figure 5).[16] The Bureau summarized the situation:


Figure 5. Machine loading with timber support.

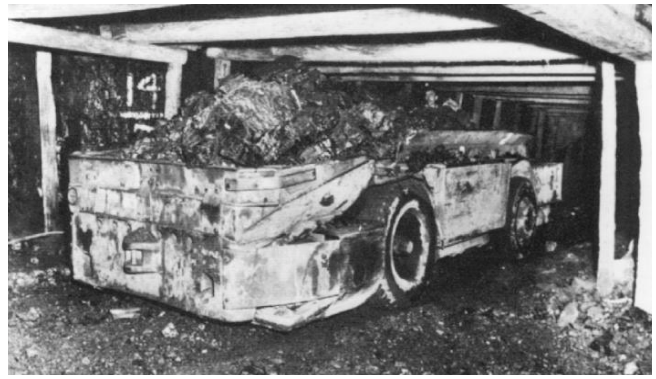

Figure 6. Shuttle car haulage with timbers.

"In many mines the simple safety post offers effective protection at the face with hand loading; after mechanical loading equipment is installed, however, safety posts may interfere with the efficiency of the equipment, and their effectiveness may be destroyed because of frequent accidental dislodgement. Too often the result is that either the safety posts are eliminated or are used only when an official is present."[17]

Noise that prevented miners from hearing the warning sounds from the roof also contributed to the hazards of machine mining.[18]

A detailed and widely reported Bureau of Mines study conducted in 1951 concluded that "mechanical operations are, to a considerable degree, more dangerous from the standpoint of roof falls" than hand loading, "notwithstanding that much closer supervision is maintained in such operations." Particularly high-risk occupations cited in the report included loading machine operator and helper, timberman, and foreman. The study also found that 74% of roof fall fatalities occurred within 25 ft of the working face, and that 3 out of 4 of these took place inby the last permanent support (between the last support and the face).[19]

The same study also attributed 89% of the roof fall fatalities to "human failure," and of these nearly two-thirds were considered the responsibility of management. It concluded that:

"These facts very definitely indicate management failure in providing sufficient roof support at working faces….Regardless of roof conditions, minimum standards of roof support suited to the conditions and mining system of each mine should be adopted and followed.…The judgment of the person should never be substituted for the minimum support required in the systematic roof support plan." [20]

The difficulties posed by traditional timber supports increased as the early track-mounted loading machines were replaced by crawler-mounted ones. When rubber-tired shuttle cars that carried coal away from the face were introduced in the late 1930's, "timbering resolved itself into setting cross-bars, because the machines required the full width of the place, leaving no room for posts."[21] The maximum span without a post increased from the 9-10 ft over track to 15-20 ft and even more (figure 6). Intersections were particularly difficult, and mines with weak top that required narrow entries or close timbering had particular problems. In fact, during this time the Bureau maintained a separate category of fatalities from "roof falls due to car or machine knocking out post." In 1946, for example, 14 deaths were attributed to this cause.[22]

Timbering began to be seen as a critical bottleneck in the mechanical mining process. Simply moving the required quantities of timber to the face was a major undertaking and caused many injuries.[23] Timber crews typically consisted of 4-5 men. To reduce the burden, equipment manufacturers and individual mining companies developed timbering machines (figure 7). These were mobile units operated by a crew of 2-3, and could carry a supply of timber posts and crossbars, cut them, and hoist them into place.[24] By 1949, Coal Age reported that timbering machines were on their way to becoming "standard loading unit equipment."[25]

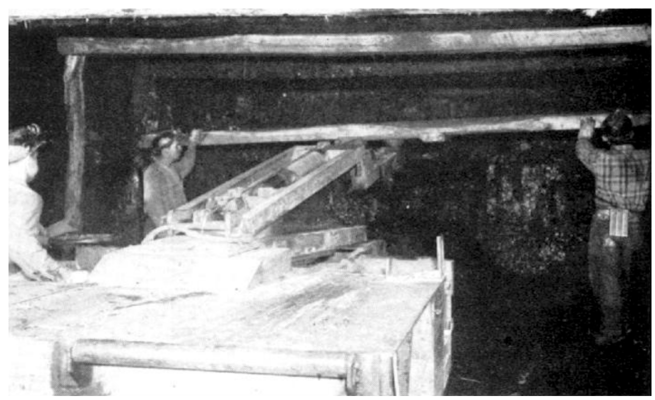
Figure 7. A timbering machine.

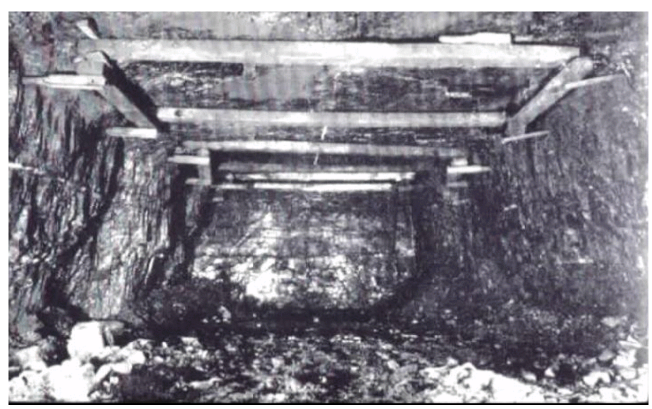
Figure 8. Pins and timbers hitched to the ribs.

As crossbars became the primary roof support, a variety of techniques were developed to install them without posts. Most involved pins or timbers that were hitched into the ribs.[26] It is impossible to view photographs of these support systems today without wondering how effective they could have been (figure 8).

Certainly they had almost no vertical stiffness, and the amount of deadweight that they could transmit to the ribs was limited, particularly where the coal was friable or fractured. Little wonder, then, the Bureau's Edward Thomas wrote in 1948 that:

> "The more progressive mining companies are continually searching for improved types of roof support that will give maximum protection and at the same time offer minimum interference with the preparation and loading of coal."[27]

"A Different and Possibly Advantageous Method of Supporting Roof"
FIRST TRIALS

Even as Thomas wrote those words, the roof bolt was emerging as the leading candidate "temporary legless support" in machine mining.[28] Roof bolts are steel rods, normally 3-6 ft long and 5/8-1 inch in diameter, that are inserted into holes drilled in the mine roof. The early bolts all used some kind of mechanical anchor at the back of the hole (today a polyester resin grout is normally used instead), and were tensioned between the anchor and the head (figure 9). As a support, roof bolts are theoretically superior to timbers because "timbers offer support after the strata they are supporting have failed; whereas roof bolts reinforce the roof rock, which contributes to its own support."[29]

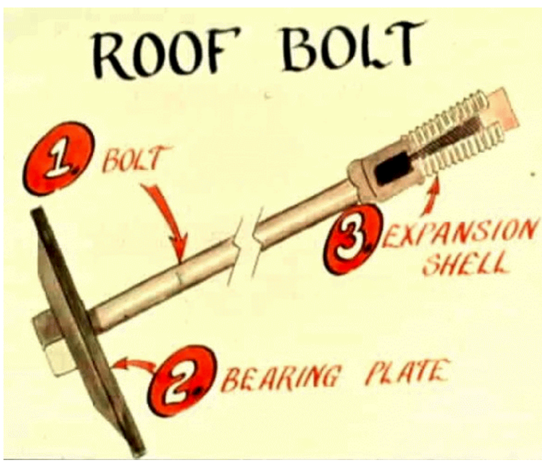

Figure 9. A roof bolt.

Roof bolts work best when they are anchored in a strong, self-supporting rock layer. In such conditions, their role is to suspend any underlying weak or loose rock. Where there is no self-supporting bed within reach, the bolts must tie the roof together to create a "beam." In general, it is much more difficult for roof bolts to build a beam than it is to suspend weak rock from one. Greater ground stresses and wider roof spans also increase the requirements placed on roof bolt systems.[30]

Some use of roof bolts was apparently recorded as early as 1905,[31] and J. C. Baldwin was credited with installing bolts in the Sagamore Colliery in southern WV in 1917.[32] The St. Joe Lead Company was the first major mining company to make extensive use of roof bolts, beginning in the 1920's.[33]

Early in 1947, C. C. Conway, Chief Engineer for the Consolidation Coal Company in St. Louis, visited one of the St. Joe mines near Bonne Terre, Missouri, and was impressed with the roof bolts he saw there.[34] He determined to try them at Consol's Mine No. 7 near Staunton IL. The roof at Mine No. 7 was a common Herrin No. 6 Seam sequence, with several feet of weak shale and "clod" drawrock beneath the extremely competent Brereton limestone. Timbering requirements were extensive, and often the drawrock collapsed before it could be supported, causing extensive dilution of the ore and a major safety hazard.[35]

The first roof bolts were installed in Mine No. 7 using hand-held stoper drills (figure 10). The anchors were expansion shells "similar to those used to support trolley wire", though slot-and-wedge type anchors like the ones "ordinarily used in the metal mines" were also employed. A section of channel iron was used as a plate. The DC air compressor was powered by a trailing cable and mounted on a truck. Two men constituted the bolting crew.[36]

For Conway, the most important feature of roof bolts was that they could be placed "as near the face as possible." Shuttle car turn-outs were also improved by eliminating some of the props that formerly supported crossbars. After placing hundreds of bolts in more than a year of experimentation, Conway concluded that the "practicality of supporting slate from a bed of limestone has been demonstrated."[37]

Figure 10. Installing roof bolts with a hand-held stoper drill.

Conway's enthusiasm was restrained, however. He introduced roof bolting not as a panacea but as "a different and possibly advantageous method of supporting roof." At this point there was "no intention to completely eliminate timbering," though timbering requirements might be reduced. "Props and other timber are the miner's barometer or measuring stick," wrote Conway; roof bolting should be considered as supplemental support "before adequate timbering is possible." He did, however, propose that roof bolts could be used to "make laminated shale homogeneous," and said that trials were already underway in other Consol mines where no strong limestone was present in the roof.[38]

"No Development in Modern Coal Mining Has Been as Spectacular and Far-reaching"
ROOF BOLTING ACCEPTED 1948-1955

The U.S. Bureau of Mines (Bureau) was apparently involved in the roof bolt trials at Mine No. 7 almost from the beginning. Early Bureau reports included roof bolts as one of several "legless supports" for mechanical loading, along with hitch timbering and peg timbering.[39] As it gained confidence in the technique, the Bureau began to advocate roof bolting enthusiastically as an accident-prevention measure.[40]

Since the Bureau was without regulatory powers, it had since 1910 "mastered the art of prodding operators into implementing new technologies that resulted from its scientific investigations."[41]* The point-man in the Bureau's roof bolt campaign was mining engineer Edward M. Thomas (figure 11). Thomas had graduated from the South Dakota School of Mines in 1926, and had served as an inspector of mines in North Dakota and an operating official in the Pennsylvania anthracite mines before joining the Bureau in 1936. In 1949, he was selected to head the Bureau's new Roof Control Section in College Park, MD.[42]

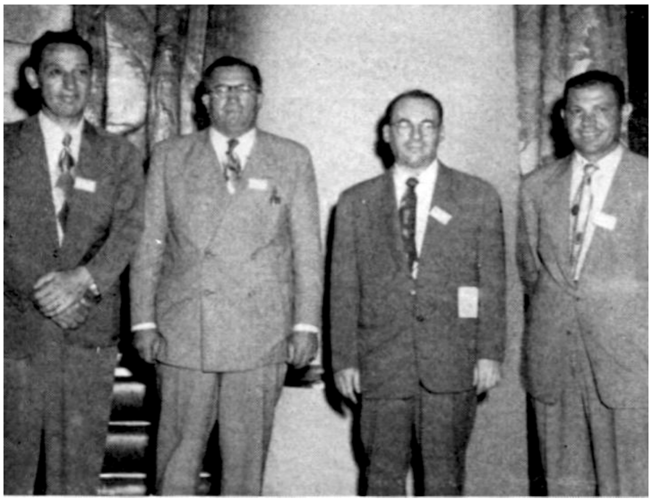

Figure 11. Speakers at the 1949 Kentucky Mining Institute. Ed Thomas is the second from right.

The Bureau's effort in encouraging roof bolting was two-pronged. On the one hand, Thomas and his associates adopted a high public profile, writing papers and giving presentations at many industry meetings. These touted the advantages of suspension supports from the standpoints of safety and efficiency. Listed safety features included:

- A systematic support "within inches" of the working face;
- Can't be dislodged by blasting or equipment;
- Improved ventilation (because of less air resistance), and;
- Reduced accumulation of explosive coal dust (because places could be cleaned more thoroughly).

Economic advantages included:

- A reduction in the time required to load a place by 15-50%;
- Potential for widening rooms;
- Faster haulage, and;
- Reduced labor cost for roof support and material handling.[43]

*Probably the Bureau's single most important achievement was rock dusting to reduce the hazard of coal dust explosions. During a 30-year campaign, the Bureau publicized both its research findings about the effectiveness of rock dust and examples of explosions that rock dust could have prevented. The Bureau was acutely aware that the expense was the primary barrier to the industry's acceptance of rock dust, and it tried to help by developing mechanized equipment to reduce the cost of applying dust. Ultimately, however, external economic incentives may have been more important than either scientific data or new legislation to the success of the Bureau's campaign. By 1925, 11 states gave worker's compensation premium credits to mines that rock dusted, and mines that didn't dust had difficulty obtaining insurance (Aldrich, 1995).

Perhaps more important than publicity was the Bureau's involvement with roof bolt trials in mines across the country. The Bureau's policy was "not to sponsor or condone the adoption of roof bolting at any mine unless it has been preceded by one or more experimental installations." In the test sites, the standard procedure was to install the normal amount of conventional timbering together with the roof bolts, and then withdraw the timber. Roof conditions were then observed over a period of several months. The test sites also "served to acquaint the workmen with the unfamiliar tools required and enables them under supervision to become expert in installing the bolts properly."[44] This cautious approach was credited with making the progress of bolting possible, because it guarded against careless installations that could have caused serious accidents and "might well have stopped all further experiments in those critical early days."[45]

The Bureau's campaign had to overcome two primary barriers to the new technology. The first was the cost and availability of the required equipment. The development of carbide alloy insert bits was essential because it made it possible to drill holes cheaply in hard rock.[46] Hand-held stoper drills were already available at most mines, but they now required a mobile source of compressed air. Many of the first mines to install roof bolts built their own cars to carry the drills, compressor, bolts, and other supplies from face to face (figure 12). In some cases, timbering machines were modified to double as roof bolters. The bolts themselves were not readily available either. In some cases, they were fabricated in the mine's own shop.

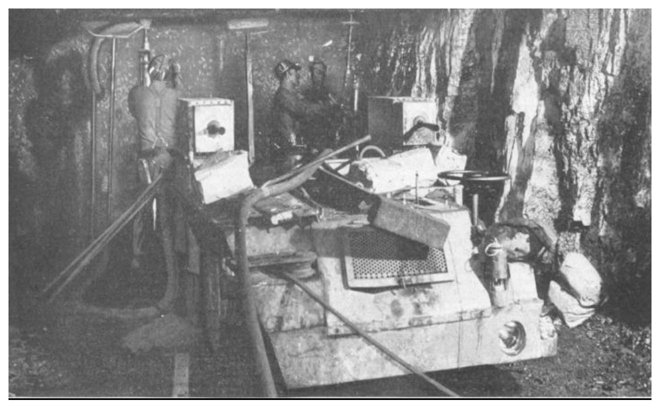

Figure 12. An early roof bolt machine.

The second barrier was psychological. Miners were used to the reassuring presence of heavy timbers, and roof bolting seemed to be "reverse in principal to the old methods,"[47] because it "appears at first glance to approximate holding oneself up by one's bootstraps."[48] Bethlehem Mines Corporation's Idamay Mine provides one example of the educational program that was required to make bolting a success in 1948. It began with training of all mine supervisors in the theory and practice of roof bolting. Top management "knew that first-line supervisors had to be sold on roof bolting before it could be tried in the mine." When the trial began, the company "started a program to sell all underground employees on the benefits of roof bolting, particularly from the safety angle."[49] In mines where "one or more officials of authority refused to accept roof bolting, the roof bolting program did not succeed,"[51] as happened at the Green Valley Mine in Indiana in 1949.[50]

Between 1949 and 1955, numerous case histories of the successful application of roof bolting from all over the coalfields were reported in the mining press (figures 13 and 14). An early article reported that three northern West Virginia mines of the Christopher

Coal Co. had reduced roof falls by 80%. Shuttle car intersections were particularly improved. The bolts were even successful in stopping "roof cutters" that "travel relentlessly and have always caused the roof to fall when they hit an intersection area."[52]

Figure 13. Shuttle car haulage with roof bolts.

Figure 14. Machine loading with roof bolts.

The results of a major Bureau study in five southern West Virginia mines were more striking. These mines "produced over two million tons of coal without a fatal accident and with only four lost-time accidents, as compared with two fatal and 71 lost time accidents over a similar period when conventional timbering methods were used. Production increases ranged from 0.86 to 10.7 tons per man shift." That these results were achieved during the dangerous process of pillar recovery made them even more impressive.[53] In northern WV, the success of roof bolting in pillar work allowed 7-10% more coal to be recovered.[54]

Roof bolts could also conquer weak roof. Zeigler Mine No. 3 was notorious for the "most treacherous roof in the Middle West," consisting of 28 ft of soft claystone under only 160 ft of cover. The mine was on the verge of shutting down because of the excessive timber requirements and the mining delays they engendered. After just three months of bolting the tonnage per manshift increased by 37%, to 22.6 tons, and accidents were also reduced.[55]

Encouraged by the Bureau of Mines, the Tennessee Coal and Iron Division of U.S. Steel introduced roof bolting to their 5 Alabama coal mines in 1948. During the next five years, 19% of their combined 66 million tons was produced beneath 3.3 million roof bolts. Roof falls claimed 49 lives in the TCI mines during this period, only one of which involved roof bolts. The fatality rate for bolted roof was, therefore, approximately just 1/10 of that beneath timbers (although 129 non-injury falls of bolted roof were also reported, mainly in intersections.)[56]*

Such figures led many safety professionals to concur with Joe Bierer of the West Virginia Department of Mines, that:

> "Herein lies a wonderful opportunity for the coal industry to bring about an epochal advance in safety for the mineworker, a humanitarian accomplishment to compare with the great social advances of recent years…No such immediately effective and readily confirmed benefit has derived from any other measure ever conceived, or devised, for safety in coal mines."[57]

The industry did not lose sight of the economic advantages either. In its 1950 Annual Review, the American Mining Congress (AMC) reported that roof bolting continued its "phenomenal growth," and that "some rather awe-inspiring estimates have been made concerning the percentage increase in production efficiency as a result of bolted roof." It concluded that a "realistic appraisal" averaged a "most worthwhile" 10-20% increase.[58] In 1954, the AMC's Committee on Roof Action wrote that:

> "No development in the history of coal mining has been as spectacular and far-reaching as roof bolting. Its first success in converting "bad top" to "good top" soon brought the further advantages of wider working places, fewer interruptions from slate falls, and, in general, improved mining efficiency and higher tonnage."

Looking back in 1956, Robert Fletcher of J. H. Fletcher & Co. wrote that "the art of roof bolting has been accepted by the coal industry with greater rapidity than any other mining change since the inception of mechanization." He attributed its success to three factors:

- Roof bolting increases safety as well as production;
- It was encouraged by the Bureau of Mines, and;
- It could be tried with a minimum of equipment.[59]

"Pressure Has Been Brought to Bear on this Department"
CHALLENGES IN PENNSYLVANIA 1949-1953

Not everyone was immediately impressed with the effectiveness of roof bolting, however. Richard Maize, Secretary of Mines for Pennsylvania, wrote to all mine inspectors and mine operators on October 14, 1949 that:

> "It has been brought to the attention of this Department that a number of operators have adopted the new method of suspension roof support recommended by the U.S. Bureau of Mines…As a result, one man has been killed in Pennsylvania and several near accidents have resulted…Under no condition will anyone be permitted to experiment with roof suspension supports at the working faces without using the standard method of timbering at that mine….If you are now using the bolt suspension method of support you must discontinue this method of control immediately…"[60]

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*Not all mines reported immediate success, however. Despite a "thorough trial," the Reels Cove mine in Tennessee abandoned roof bolting because the disintegration of the roof shale over time "loosened the bolts and made them useless." Timber was also much cheaper there, at $0.10 per post against $1 per bolt. (Coal Age [1951]. "Continuous-Face Mining." June, p. 80.)

That Fall, it was reported that PA inspectors had halted work on the Porter Tunnel mine until some 500 ft of roof bolt supports could be replaced with conventional timbering.[61]

A battle royale was soon in process. Pennsylvania operators clearly did not want to be denied access to a new technology that their competitors were rushing to adopt. Maize was also in an awkward position because the Bureau, other state agencies, and apparently even many of his own inspectors felt favorably towards the technique.

Maize did not give up easily, and he seemed to have the law on his side. On April 11, 1950, he wrote another Circular Letter to his inspectors:

> "Pressure has been brought to bear on this Department from the Operators urging that we permit the new method of suspension roof support recommended by the USBM without the use of conventional timbering… The Bituminous Mining Laws state: 'The mine foreman shall direct and see that every working place is properly secured by props or timbers'.…As the law states that the roof must be supported by timber, it can logically be assumed that the securing of the working place must be by timber."[62]

A compromise was soon achieved, however. A procedure was developed whereby a mine could be granted a roof bolting permit following the favorable report of a Committee of inspectors. An example was provided in the 1950 Annual Report of the PA Dept of Mines. The Renton No. 6 Mine of Consolidation Coal Co. had been bolting on an experimental basis since 1949. Nearly 3 miles of entry had been bolted, fenced off, and the timbers were removed. The entire area was reported to be standing without any roof falls or even indications of weight, while many falls had occurred in the adjacent timbered area. Based on these findings, roof bolting was approved at Renton for a 4 ft by 4 ft pattern, and with restrictions on miners going beyond supports.[63] In August of 1951, the PA Attorney General ruled that roof bolting was permissible in lieu of timbering, but only if permission was obtained first from the Secretary of Mines.

By 1954, the Pennsylvania Department of Mines had joined the ranks of the true believers:

> "From the reports of our inspectors it has been learned that neither a serious or a fatal roof fall accident has occurred under 885 miles of area that has been roof bolted. This is a remarkable achievement considering the fact that 70% of all fatal accidents in PA mines were caused by falls of roof. We realize that roof bolting may not be a cure all, however, we cannot overlook experience, and this experience convinces us that roof bolting has materially aided roof control. More and more people are becoming roof bolt conscious and we hope the trend will continue."[64]

By this time, 72 of the largest PA mines, representing more than half of the tonnage produced in the state, were using roof bolts for at least some of their production.

"Roof Bolts Are Not Sky Hooks"
DISAPPOINTMENT 1955-1960

By the mid-50's, it was clear that timber supports would soon go the way of the pick and shovel. In 1957, the Bureau estimated that more than 50% of all underground bituminous tonnage was produced beneath roof bolts.[65] The spread of roof bolts should have been accompanied by an equally dramatic drop in roof fall fatalities. As late as 1954 the Bureau had estimated that the fatality rate on sections supported by conventional timber was 5½ times higher than on roof bolted sections.[66]

Yet overall fatality rates stubbornly refused to go down. Responding to the 1955 statistics, Thomas wrote:

> "Roof bolting's influence on the over all roof fall injury picture was disappointing when one considers that the use of bolts in coal mines increased by 1/3 during the year…There were as many fatalities (five) from failures in bolted roof in 1955 as the total for 1948-1954."[67]

Thomas advanced two explanations for the frustrating lack of progress. The first was that when miners go beyond the last support they are unprotected, regardless of what type of support is used. A 1954 Bureau study had again found that more than 50% of roof fall fatalities occurred in the unsupported space between the last row of supports and the face.[68] The following year, Thomas found that an even higher percentage of the fatalities on roof bolted sections took place in what he called the "danger zone." One obvious solution was the safety post:

> "No responsible mining official would suggest that safety props or jacks be eliminated as long as there is any chance that anyone will enter it [the danger zone] to perform his work." [69]

Thomas also advocated work practices that kept workers out of the danger zone, and endorsed the use of automatic safety supports on roof bolting machines.

The second explanation for the lack of progress was that "many mines are now bolting where the method is marginal in the sense that perfect anchorage cannot be obtained."[70] Here Thomas was returning to a warning he had sounded as early as 1951, when he wrote:

> "In many instances the increase in productivity [with roof bolts] has been almost incredible and has led many mining men to conclude that through some hocus-pocus they can now cast aside many or all of the time-proven rules of good mining practice. If this tendency is not counteracted, it could easily result in an increase of roof fall accidents…"[71]

Elsewhere, he said that "Roof bolts are not 'sky hooks' and they do not eliminate the weight of the roof."[72]

Looking back, it seems clear that simply replacing timbers with bolts would not be sufficient to substantially reduce roof fall rates. The success of any support system in a particular application depends not just on the *type* of support, but also on the density of the pattern, the capacity of each unit, when they are installed, the quality of the installation, and many other factors including the span, the rock quality, and the ground stress.[73]

Simply stated, *roof bolts can only prevent roof falls if enough of them are installed*. That costs time and money. The mine operator's natural tendency was to adjust the expenditure to achieve an *acceptable* level of roof fall risk. Unless the mining culture was changed to reduce the acceptable level of risk, competitive pressures would mean that the new technology would be adapted to obtain the same results as before.

Leon Kelly, a Bureau engineer in Vincennes IN, described this process perfectly in remarks he made to the 1950 Annual Meeting of the IL Mining Institute. He cited examples from three mines in his own experience in which the level of support had been reduced:

- Four-ft bolts had originally anchored in limestone, suspending 2-ft of weak mudstone. The mudstone thickened to 5 ft, but the mine kept using 4-ft bolts.
- Very weak roof was originally supported by 5-ft bolts in a 4-bolts per row pattern. When that proved successful, the mine reduced the bolt length to 4-ft on a 3-bolt pattern. Approximately 6% of the newly bolted roof now collapsed, but the operator judged that acceptable.
- A mine operator reduced the number of bolts per row from 3 to 2, because “in most cases the bolts held the roof long enough for them to work the place out, and he didn’t feel justified in spending the additional money.”

Kelly summed up:

> “The important thing [the cases] show is the deliberate trend. In each case, when bolts were first used at the mine, everyone was more or less afraid of them and the pattern that was adopted was followed religiously. As time went on, and none of the bolts fell out, they were taken for granted and it was assumed that bolts would hold up the roof as long as there were bolts in the roof. Some operators are beginning to tell me that we are all overbolting, and naturally when they feel that way they will reduce either the number of bolts or the length of the bolts they use…. If failures are accepted as a calculated risk, it is only a matter of time until a serious accident occurs…”[74]

By 1960, roof bolting was no longer expected to perform miracles. A Campaign to Prevent Injuries from Roof Falls in Coal Mines was initiated that year under the auspices of the National Safety Council, and was sponsored by Federal and State agencies, the United Mine Workers of America, coal associations, safety organizations, and others.[75] Full-page articles on how to reduce the number of roof falls were published in the Mining Congress Journal during each month of that year, yet the strategy of abandoning timbers in favor of roof bolts was never suggested. Instead, the campaign focused on a number of older themes: Systematic roof support plans, enforcing compliance with the plans, use of safety posts, and not going inby supports (figure 15).[76] As Coal Age magazine said:

Figure 15. Materials from the 1960 Campaign to Prevent Injuries from Roof Falls in Coal Mines.

> “Few are the mines that cannot cut accidents from falls of roof, face, and ribs more than 50% by the intensive, continuous application of well-known basic principles. All that is necessary is to do it.” [77]

Despite the campaign, the roof fall fatality rate climbed to its post-war peak in 1960.

“A Health Hazard Is Created While Attempting to Eliminate the Hazard from Rock Falls” SILICA DUST AND ROOF BOLTING

Drilling creates dust. While the health dangers of coal dust had been disputed for more than a century, there was no question about the hazard of silica dust. The Bureau of Mines had identified silicosis as a major hazard for metal miners as early as 1917.[78] Nearly 2000 tunnel workers, many of them ex-miners, had been killed or disabled by silicosis at Hawks Nest Mountain in WV during the 1930's.[79] By the late 1930’s, most states recognized silicosis in their workmen’s compensation laws.[80]

The Bureau of Mines recognized the need for dust control when drilling for roof bolts from the very beginning. Their studies showed that coal mine roof strata contained an average of 31% free silica, with typical values of 26% in shale and 55% in sandstone.[81] The accepted technique for controlling drilling dust in metal mines was to force water up the drill steel to the bit. The Federal Mine Safety Code specifically required the use of water where rock was drilled with percussion drills.[82] Wet drilling was enforced so rigidly in metal mines that “it was taken as a matter of course, even though drilling vertical holes is a sloppy, disagreeable task.”[83]

Many in the coal industry clearly understood the risks as well. At a panel on roof bolting at the 1949 Annual Meeting of the Kentucky Mining Institute, engineers from the Berwind-White Coal Company, the West Kentucky Coal Company, and the National Coal Association joined the Bureau’s Thomas in urging mine operators to give wet drilling serious consideration.[84]

The Bureau publicized research that showed dry drilling, with either pneumatic stoper or electric rotary drills, could result in silica dust concentrations up to *200 times* the recommended level of 5 million particles per cubic ft of air. Such concentrations were a serious menace to not just the drill operators, but also anyone working downwind in the return air. Wet drilling, on the other hand, was found to result in acceptable levels of dust.[85]

Wet drilling never caught on, however. In a bluntly honest assessment, Thomas explained how the Bureau’s decision to allow dry drilling in the initial roof bolting trials had contributed to the problem:

> “In the first installations of roof bolts in coal mines the possibility of failure was of great concern to mine officials. Frankly, we considered it more important to prove the practicability of the method, leaving dust control a secondary consideration. When roof bolting became popular, it was difficult to convince new users that dust control measures should be adopted, especially when the original installations had not considered such provisions….The coal miner, regardless of any explanation that wet drilling is standard practice in metal mines, is unimpressed and wants no part of such a sloppy, disagreeable task. It is difficult for him to visualize the silicosis hazard or to take it seriously”[86].

In an address to the 1950 Illinois Mining Institute, J.J. Forbes, the Bureau's Chief of Health and Safety, said that "without some means of controlling dust a health hazard is created while the attempt is being made to eliminate the hazard from falls of rock." He reported on a meeting held in Washington DC in which representatives of machinery manufacturers, coal-mine operators, and mine workers had discussed dust control measures in connection with roof bolting.[87] Following this meeting, the Bureau began an extensive program of testing dust collecting systems for performance. Yet as late as 1957, the Bureau reported that of the 424 mines using roof bolts, just 8% employed water to allay dust, 35% employed dry dust collectors, and nearly half employed no means of dust control other than respirators (figure 16).[88] An industry consultant provided one explanation for the lack of progress: "The application of dust control to bolt drilling operations generally adds to the time and cost of the bolting and often delays the mining cycle."[89]

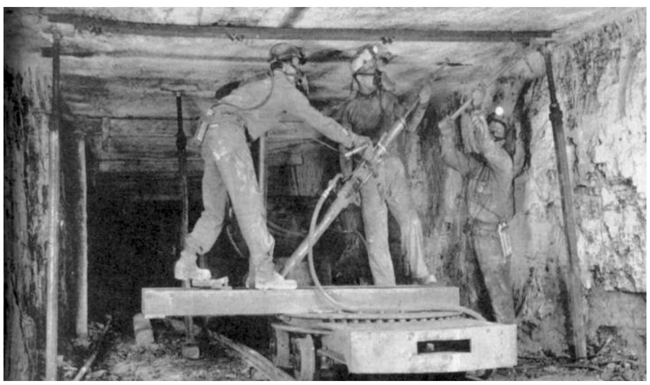

Figure 17. Dry drilling using respirators for dust protection.

There is little doubt that the prevalence of occupational lung disease among the generation of miners who worked in the dusty, mechanizing mines of the postwar period was higher than among most others in the past.[90] Unfortunately, it seems that silica dust from roof bolting must have contributed to this terrible human toll.

EPILOGUE

What is the verdict on roof bolting during the 1950's? Certainly it was a success, if it is judged by the speed with which it was adopted or the effect that it had on the economics of mining. But those were not the criteria used by technology's most public advocates:

> "Safety has been the principal consideration of the inspection and other accident-prevention agencies that have endorsed and promoted roof bolting during the past several years."[91]

On these grounds, the results are mixed. Certainly bolting did not live up to its early high expectations. The total number of roof fall fatalities declined, but three out of five mining jobs also disappeared between 1948 and 1960. Each of the remaining miners actually had a greater chance of being killed in a roof fall than his counterpart in 1948. Moreover, roof bolting had introduced a vicious new hazard, silica dust.

However, it would be unreasonable to lay the blame for the erosion of safety at roof bolting's door. The 1950's were a time of severe economic stress for the mining industry. The coal boom that began during WWII had ended, and production was decreasing and prices were declining as competition from strip mining and other fuels was growing. The UMWA under John L. Lewis collaborated with the largest coal companies to raise miner's wages, forcing the pace of mechanization.[92] Subjected to such extreme competitive forces, the mining industry was unlikely to radically improve its safety culture on its own. Little external pressure to improve safety was applied either, as the 1952 Federal Coal Mine Safety Act was a weak law that did little to stiffen regulation.[93]

The 1960's saw stability return to the mining industry. America's demand for electric power was increasing, and coal was the fuel of choice for new generating stations.[94] Roof fall fatality rates fell back to the levels of the late 1940's.

Then, on Nov. 20,1968, the Farmington Mine was destroyed in a massive gas and dust explosion. 78 miners died, and coal mining was changed forever. When Richard Nixon signed the Federal Coal Mine Health and Safety Act of 1969, federal inspectors were given much expanded enforcement powers, and a detailed set of health and safety standards was made mandatory for all mines.[95] Systematic roof support plans were finally required, with strict guidelines regarding bolt spacing, bolt length, entry width, and other ground control parameters. Working under unsupported roof without safety posts was banned.

The results were quick and dramatic. In the eight years following 1968, roof fall fatality rates plummeted by two-thirds, and they maintained that level for the next decade. The improvement might have been due to regulatory enforcement, or to changes in safety standards implemented by the operators themselves. But there can be little doubt that the tidal wave generated by Farmington transformed the safety culture of underground mining.

Today, roof bolting is the universal primary roof support. Indeed, it is hard to imagine modern coal mining, in the U.S. or internationally, without it. Modern roof bolting machines efficiently collect nearly all the silica dust. Yet, roof fall fatality and accident rates seem to have reached another plateau.[96] New types of bolts and other supports continue to be introduced and adopted by the mines, with little overall effect on safety. Perhaps the lesson from the introduction of roof bolting is that improved technology is not enough, it must be accompanied by a change in the way safety is viewed. Much technology for preventing roof falls and protecting miners is already available. The challenge now for the mining community is to decide that the current risk of roof falls is unacceptable.

ENDNOTES

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